
First 1 km coupled simulations
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Temperature in °C
Credit: D. Klocke (MPI-M), R. Redler (MPI-M), F. Ziemen (DKRZ)

Climate Sensitivity (and Clouds)

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… unpublished ideas

The standard paradigm …

$$S = -F/\lambda, \quad \text{with } \lambda = \sum_i \lambda_i$$

… based on which we try to reason about the values of F and the λ_i

The standard paradigm … (clouds)

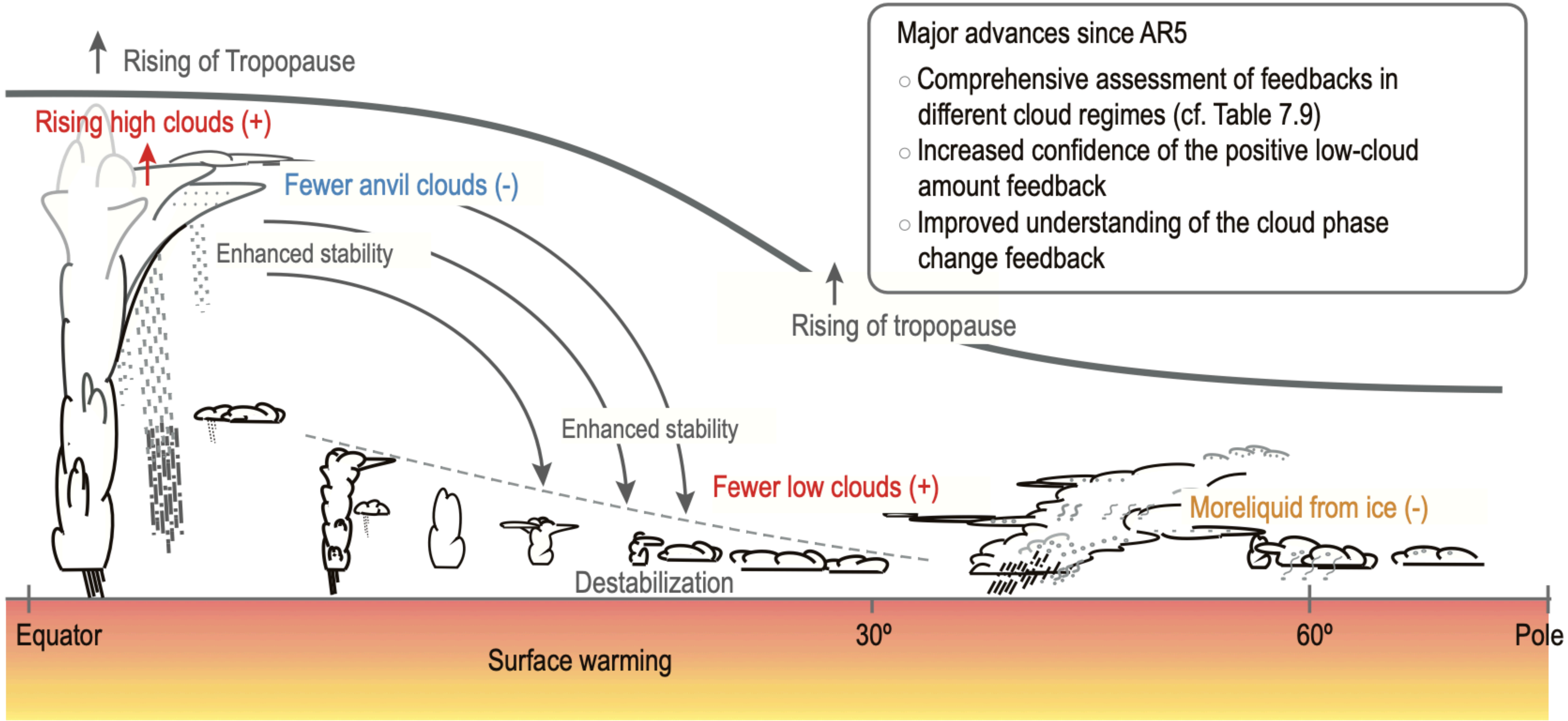


Figure 7.9 | Schematic cross section of diverse cloud responses to surface warming from the tropics to polar regions. Thick solid and dashed curves indicate the tropopause and the subtropical inversion layer in the current climate, respectively. Thin grey text and arrows represent robust responses in the thermodynamic structure to greenhouse warming, of relevance to cloud changes. Text and arrows in red, orange and green show the major cloud responses assessed with *high*, *medium* and *low confidence*, respectively, and the sign of their feedbacks to the surface warming is indicated in the parenthesis. Major advances since AR5 are listed in the box. Figure adapted from Boucher et al. (2013).

Chpt 7 IPCC AR6 (Forster et al 2021)

The standard paradigm … (quantifying clouds)

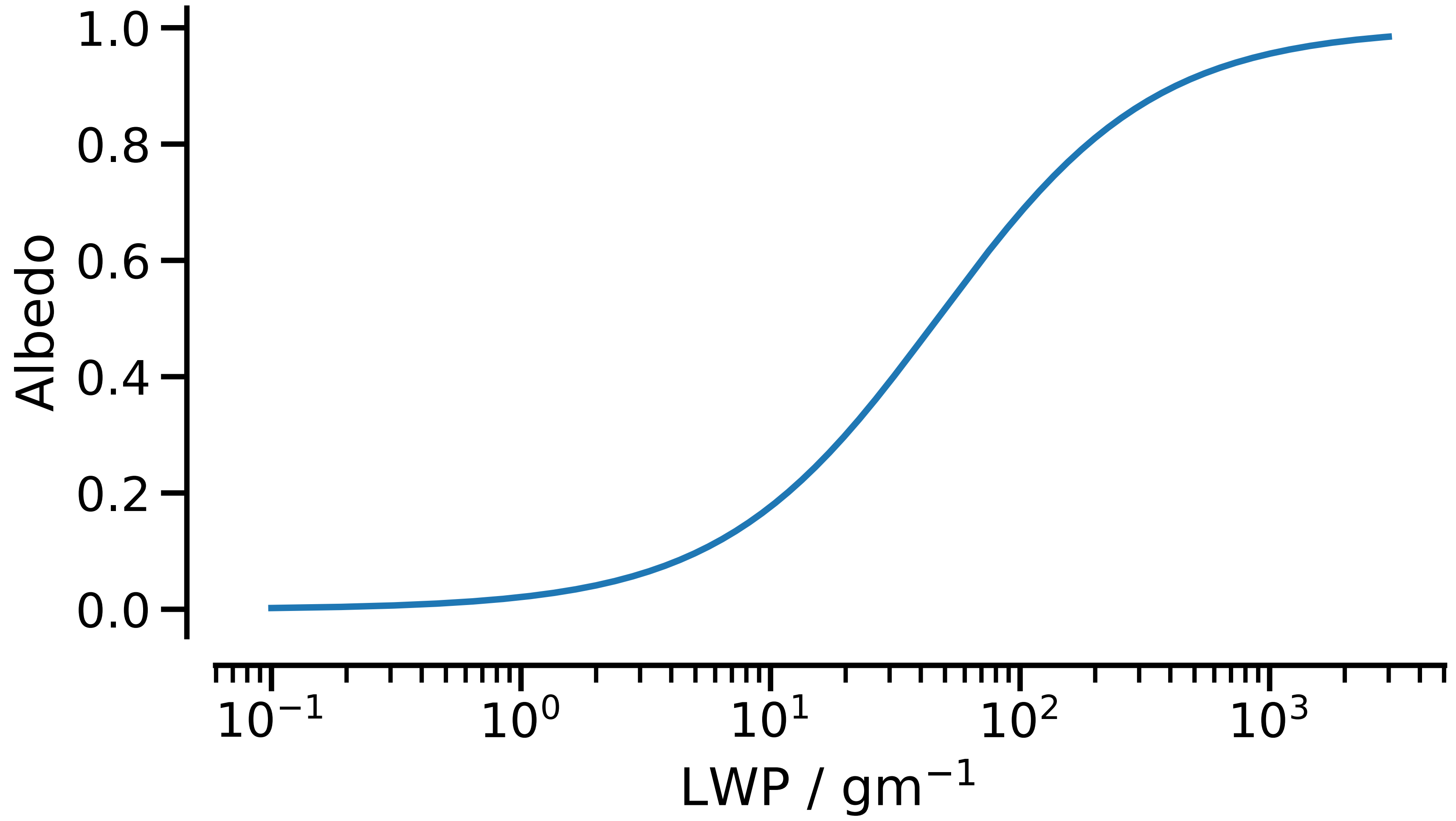
Feedback	AR5	AR6	
High-cloud altitude feedback	Positive (*high confidence*)	Positive (*high confidence*)	0.22(12) $\mathrm{Wm^{-2}\,K^{-1}}$
Tropical high-cloud amount feedback	N/A	Negative (*low confidence*)	-0.15(20) $\mathrm{Wm^{-2}\,K^{-1}}$
Subtropical marine low-cloud feedback	N/A (*low confidence*)	Positive (*high confidence*)	0.20(16) $\mathrm{Wm^{-2}\,K^{-1}}$
Land cloud feedback	N/A	Positive (*low confidence*)	0.08(8) $\mathrm{Wm^{-2}\,K^{-1}}$
Mid-latitude cloud amount feedback	Positive (*medium confidence*)	Positive (*medium confidence*)	-0.03(5) $\mathrm{Wm^{-2}\,K^{-1}}$
Extratropical cloud optical depth feedback	N/A	Small negative (*medium confidence*)	0.01(5) $\mathrm{Wm^{-2}\,K^{-1}}$
Arctic cloud feedback	Small positive (*very low confidence*)	Small positive (*low confidence*)	0.09(10) $\mathrm{Wm^{-2}\,K^{-1}}$
Net cloud feedback	Positive (*medium confidence*)	Positive (*high confidence*)	0.42(30) $\mathrm{Wm^{-2}\,K^{-1}}$

Classic Climate Sensitivity Estimate: $\mathrm{S} = -F/\lambda$, with $F = 3.93(47)\mathrm{Wm}^{-2}$ and $\lambda = -1.16(40)\mathrm{Wm}^{-2}$ gives $S = 3.4\mathrm{Wm}^{-2}$, which attributes 0.8 K or about 25 % of the warming to clouds.

Mostly a question of more or less .. a surprisingly shortwave point of view

Chpt 7 IPCC AR6 (Forster et al 2021)

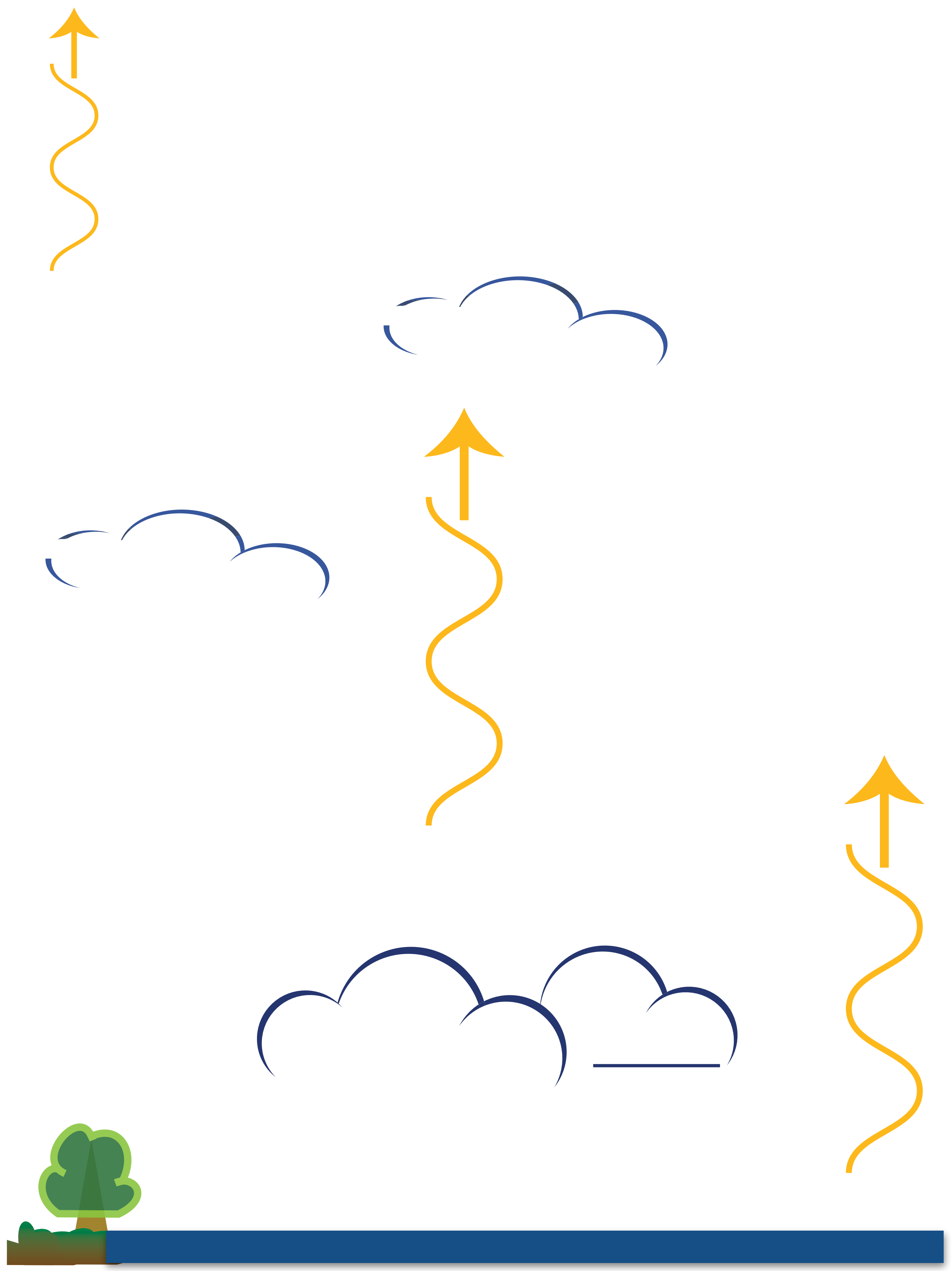
which even for the shortwave can be misleading



A great many of the clouds we care about have LWP < 20 gm-2

Mieslinger et al., ACP (2021)

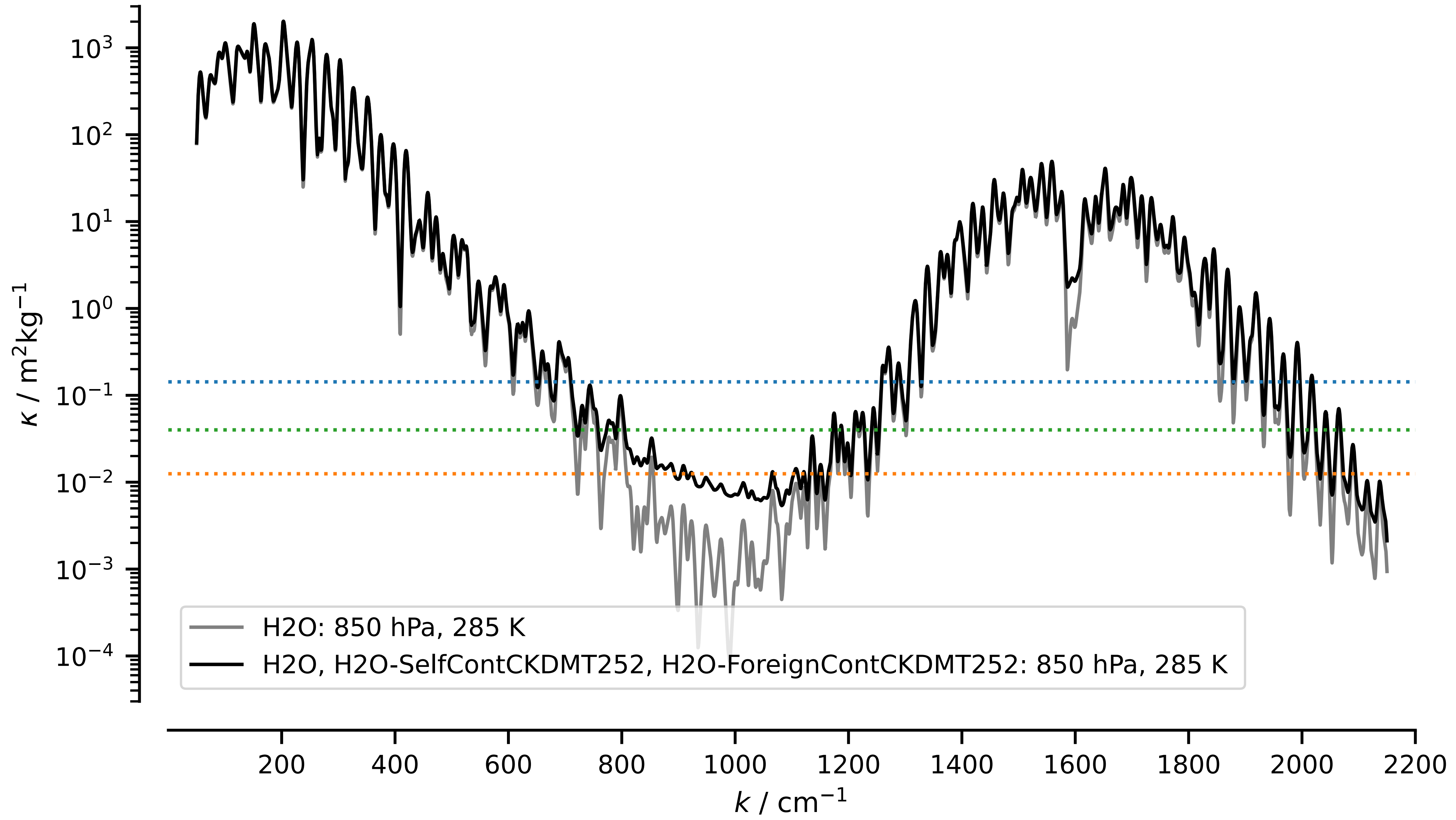
How should we think about clouds?

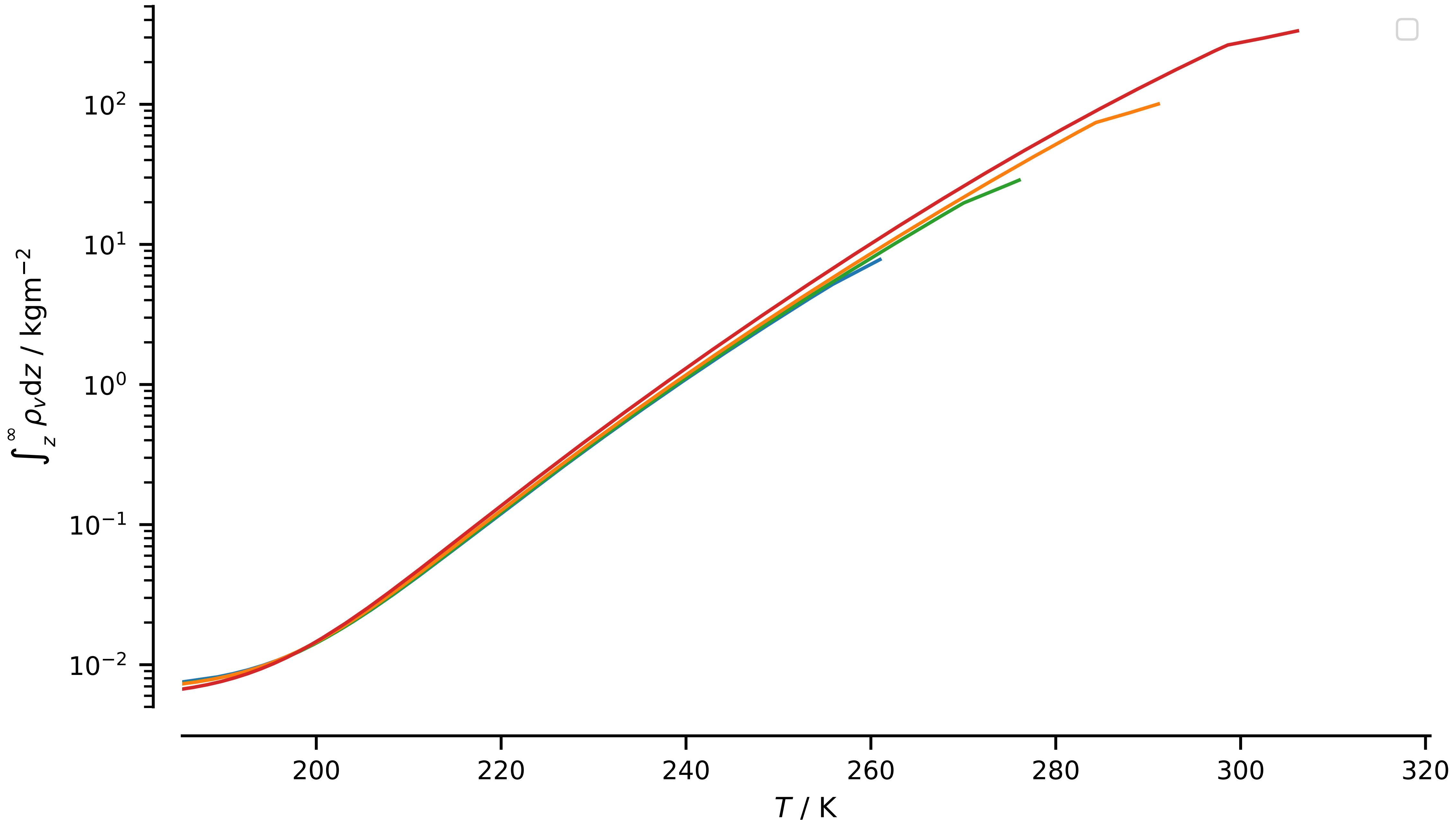


Based on their temperature and effective coverage in the LW, and on their albedo in the SW

Mieslinger et al., ACP (2021)

How should we think about climate sensitivity

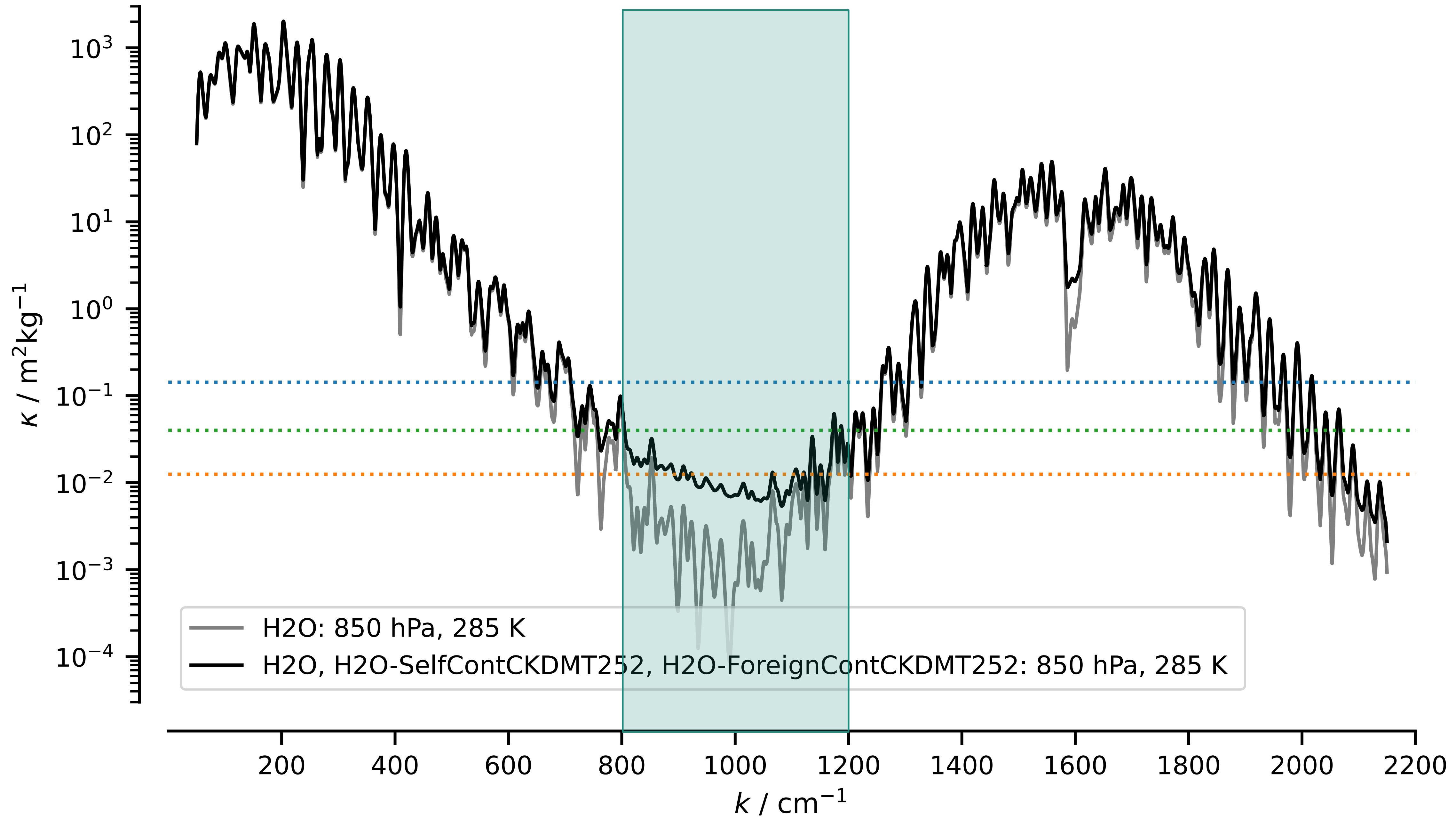




… by understanding how clouds change something we understand, i.e., the clear sky

Column water vapor above a given temperaturefollowing a moist adiabat with constant relative humidity, below cold point. Specific humidity constant above cold point

Water vapor masking (Simpson)

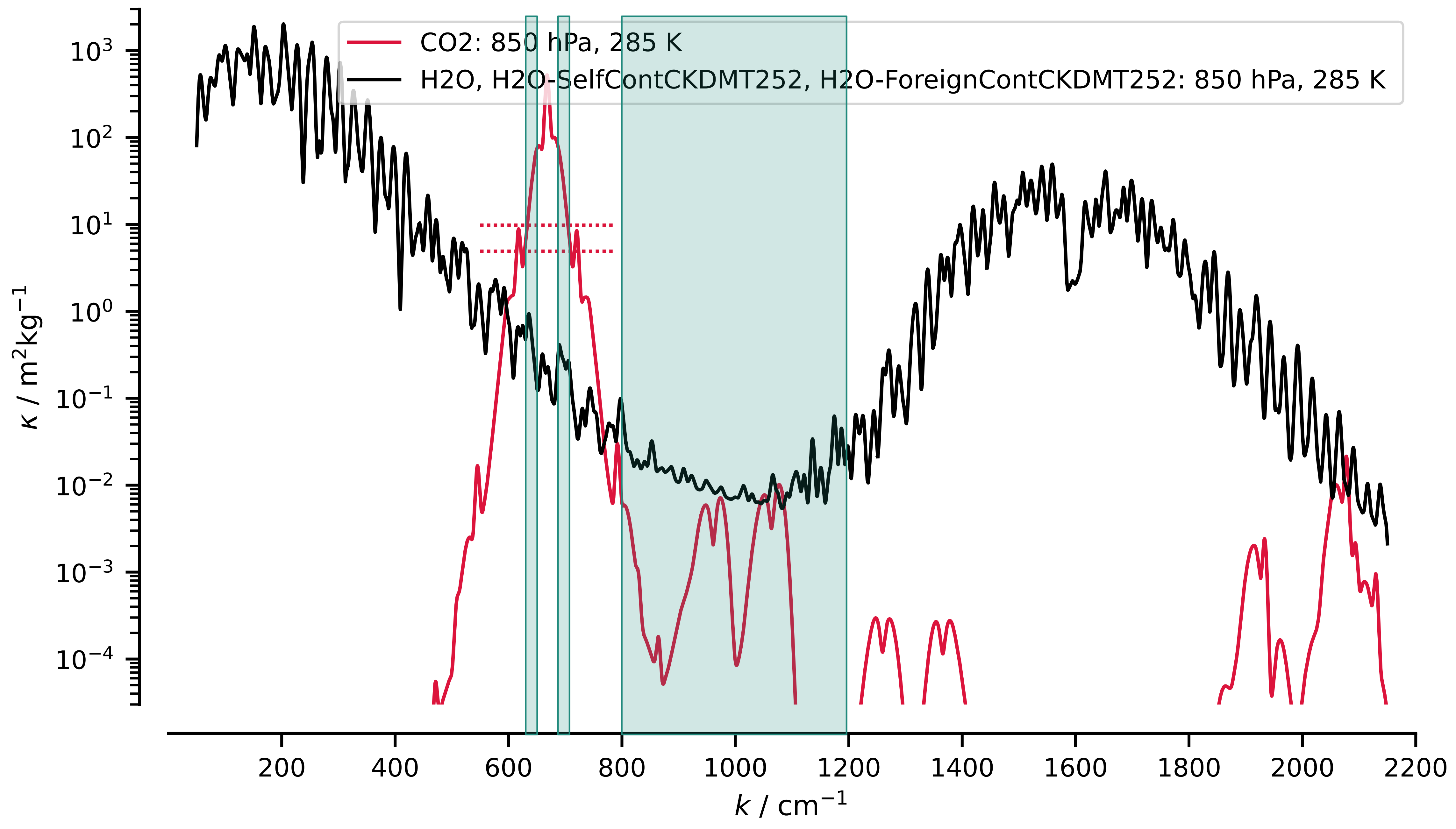


$$\lambda \approx \frac{-\pi}{\delta T}\int_{800}^{1200}\left[\mathscr{B}_{\tilde{\nu}}(T+\delta T)-\mathscr{B}_{\tilde{\nu}}(T)\right]\,\mathrm{d}\tilde{\nu}$$

$$\approx -1.75\ \mathrm{Wm^{-2}K^{-1}}$$

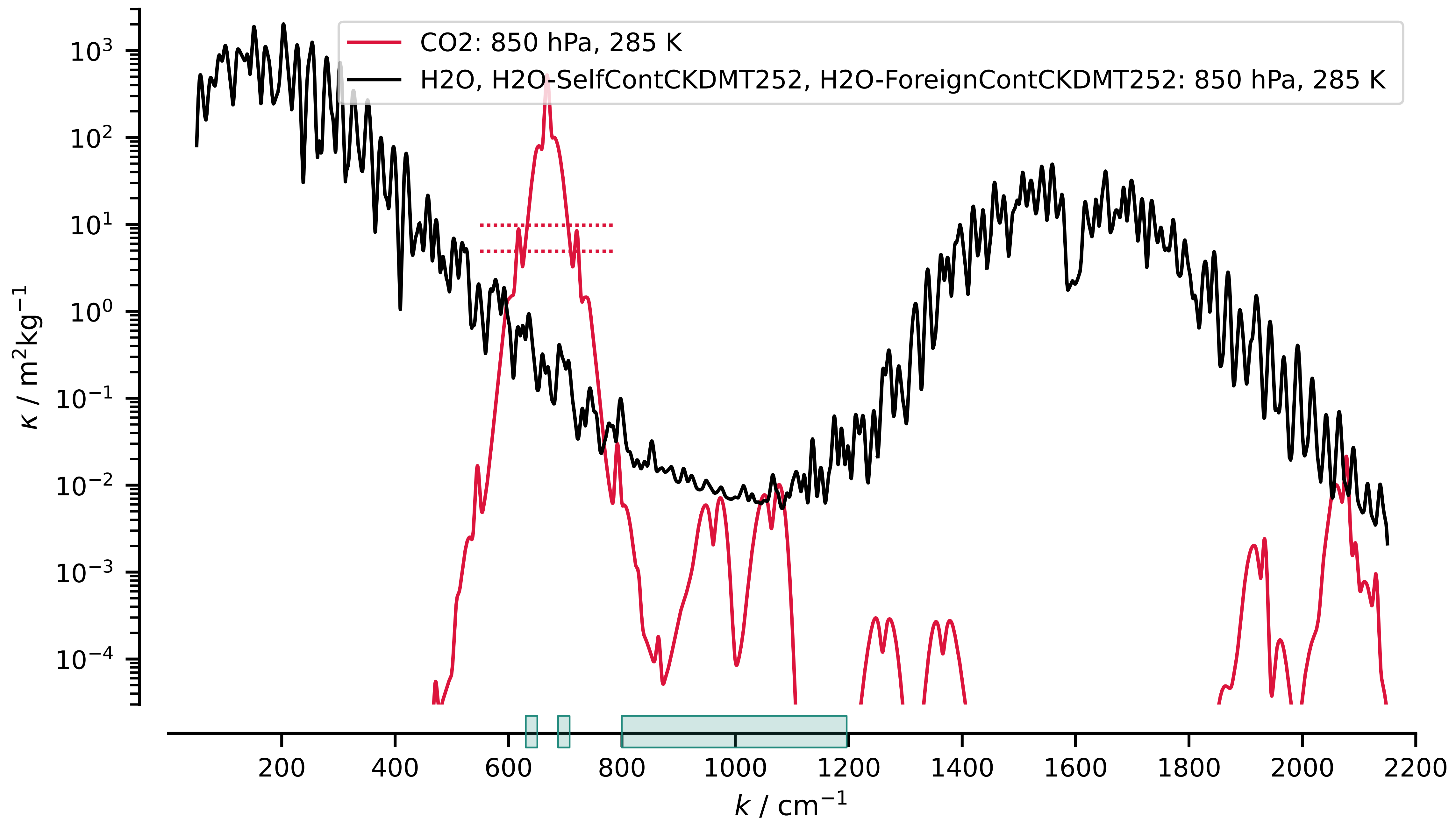
alternatively integrate over all $\tilde{\nu}$ and weight by $e^{-\tau_{\tilde{\nu}}}$

CO_2 forcing, unlike solar forcing, also adds to its cooling potential



CO_2 provides support for a more negative feedback parameter, and teaches us how to think about clouds …

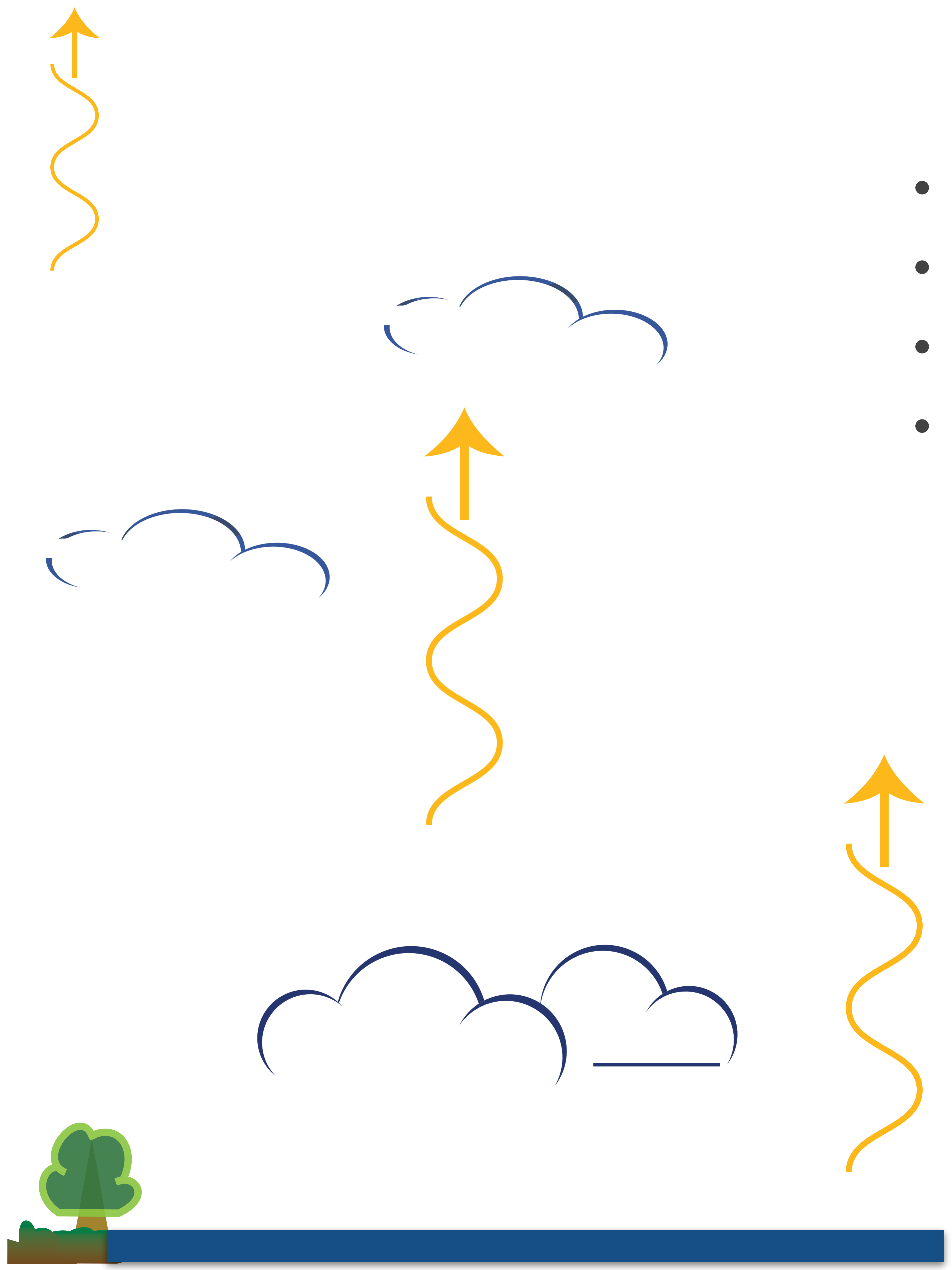
CO_2 forcing, unlike solar forcing, also adds to its cooling potential



Defines the support for $\delta\mathscr{B}_{\tilde{\nu}}$

CO_2 provides support for a more negative feedback parameter, and teaches us how to think about clouds …

Through the way they struggle for the spectral landscape



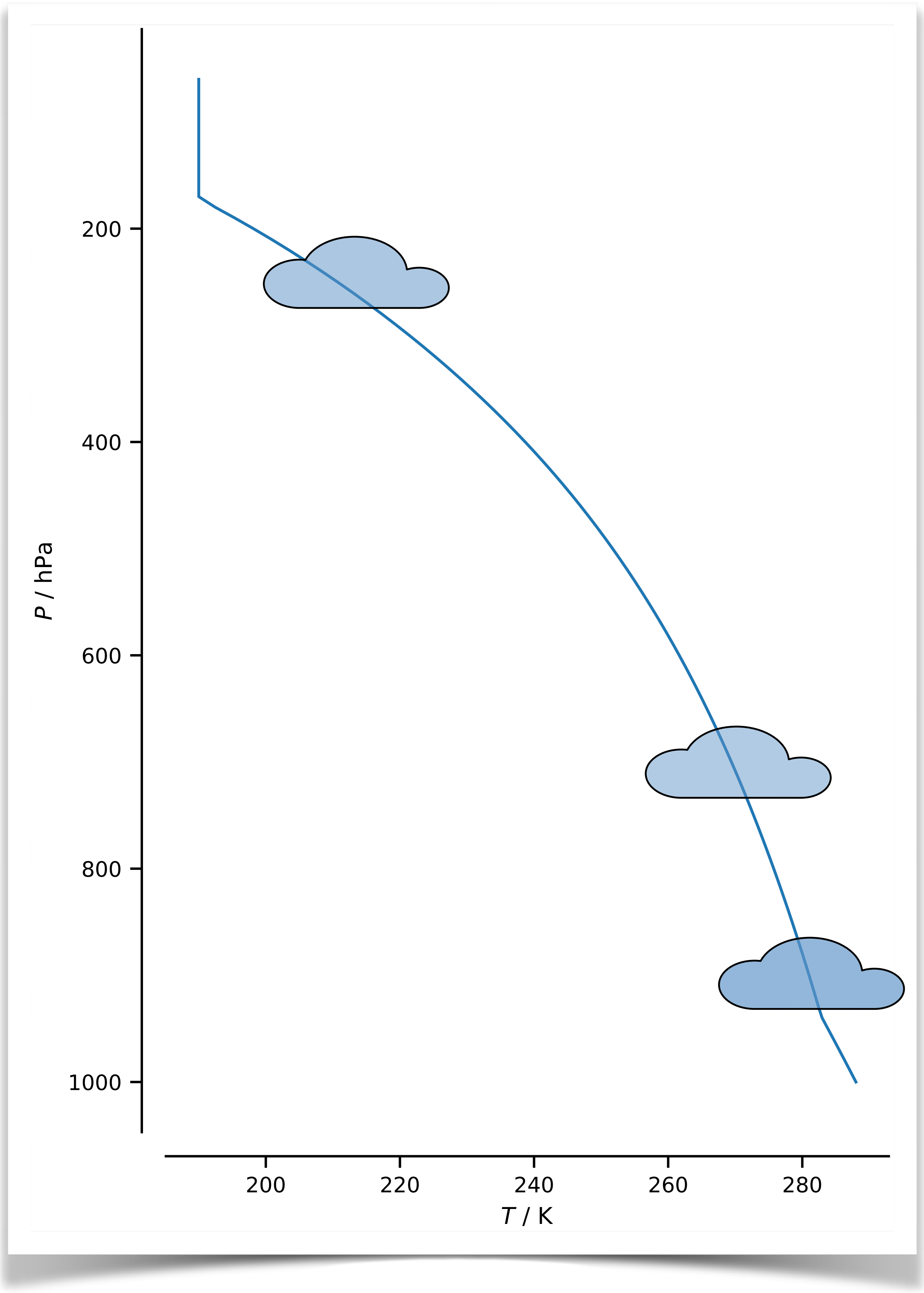
- $\delta T_{\mathrm{cld}} = 0$ implies reduced support for $\delta \mathscr{B}_{\tilde{\nu}}$
- $\delta T_{\mathrm{cld}} > 0$ implies increased support for $\delta \mathscr{B}_{\tilde{\nu}}$, more so for higher clouds.
- $\delta T_{\mathrm{sfc}} > \delta T_{\mathrm{cld}}$ diminishes the spectral response in the window
- more support for $\delta \mathscr{B}_{\tilde{\nu}}$ implies an increased radiative response to warming, and vice versa

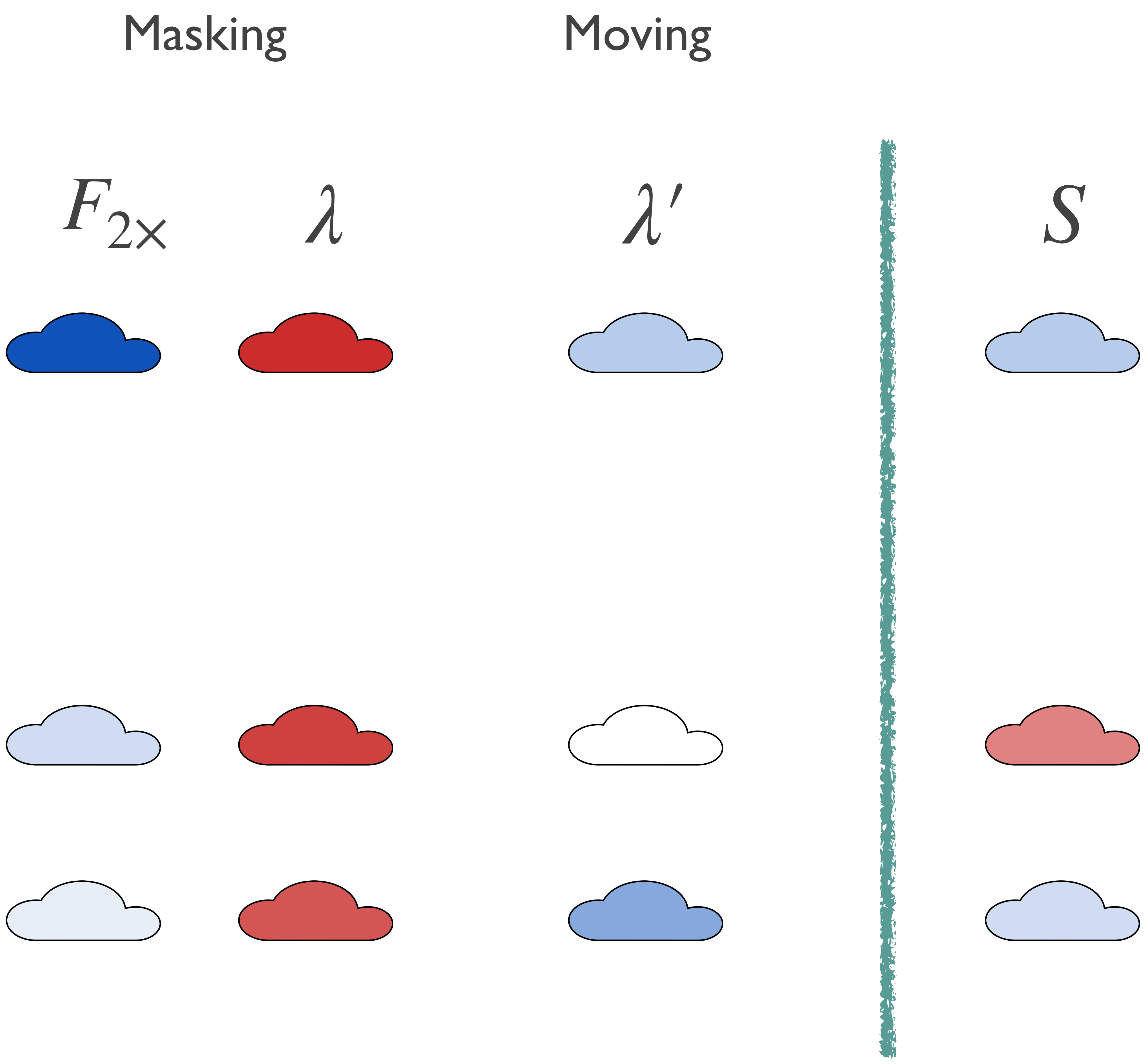
- High clouds for which $\delta T_{\mathrm{cld}} > 0$ reduce S
- Low clouds for which $\delta T_{\mathrm{sfc}} > \delta T_{\mathrm{cld}} > 0$ reduce S.
- High clouds reduce the forcing

Whereby T_{cld} determines how much of the spectral landscape clouds control

Based on their temperature effective coverage in the LW, and based on their albedo in the SW

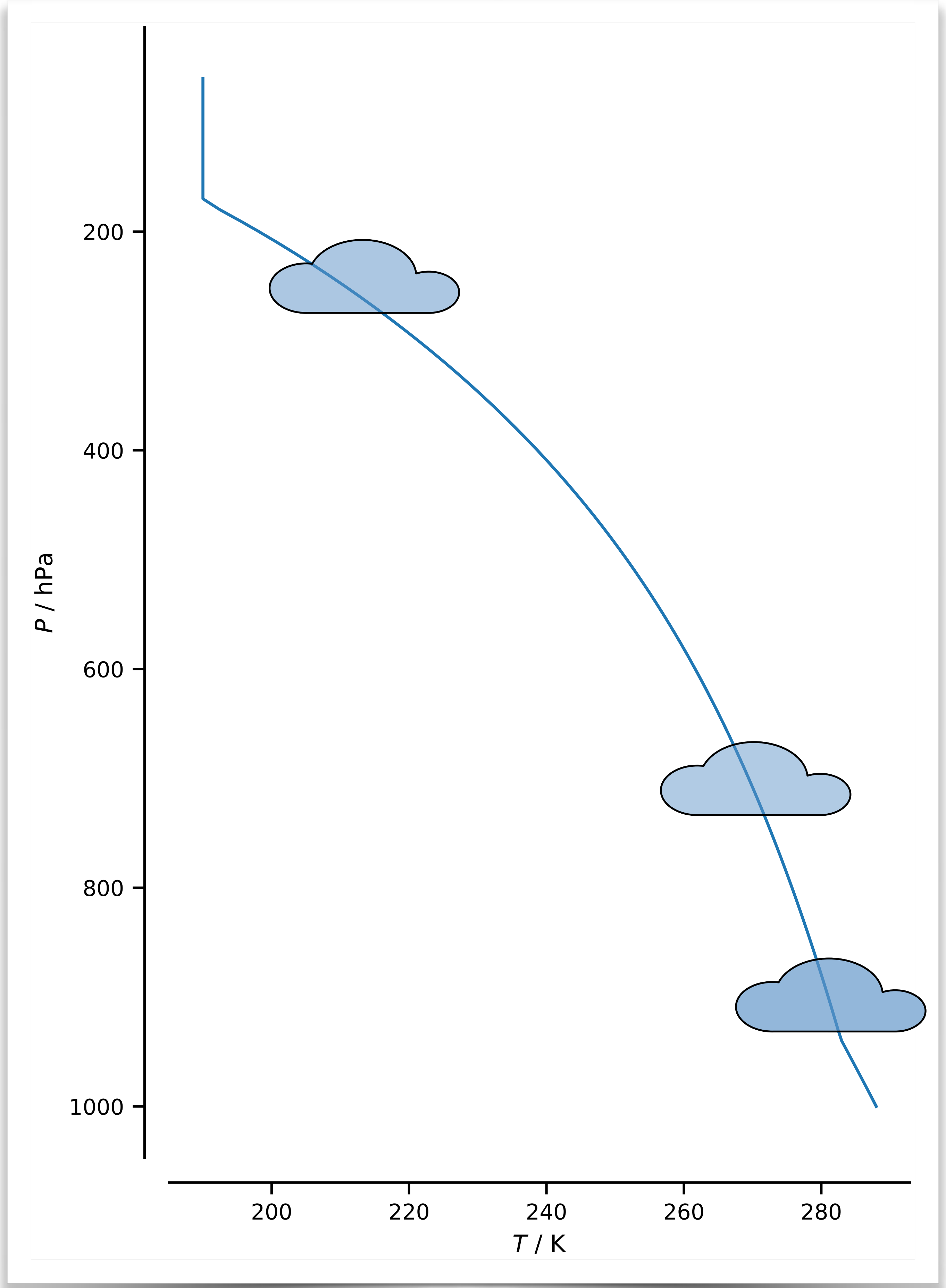
A tally sheet

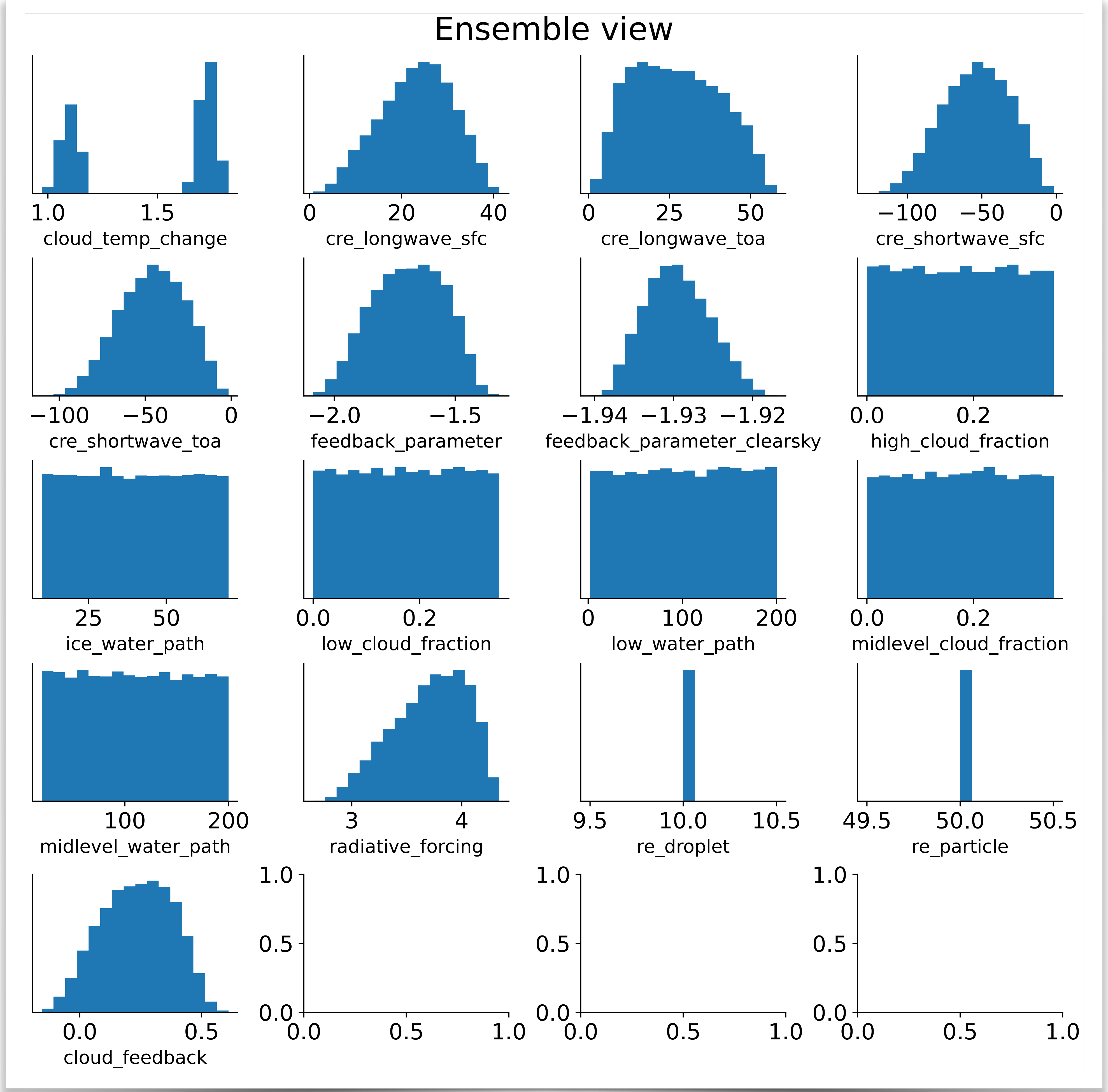




High and low clouds cool a bit, midlevel clouds warm,

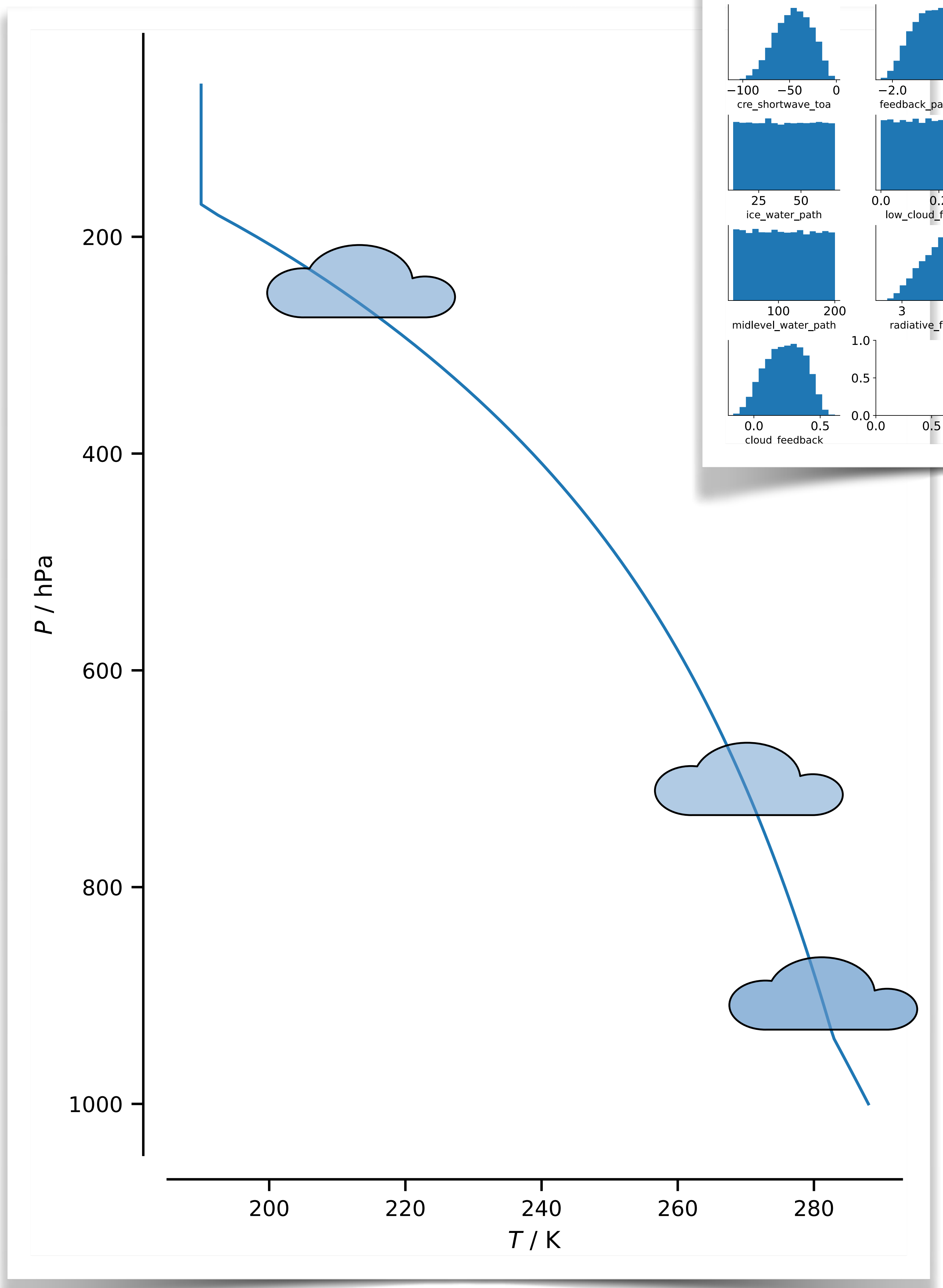
What do more detailed calculations say?

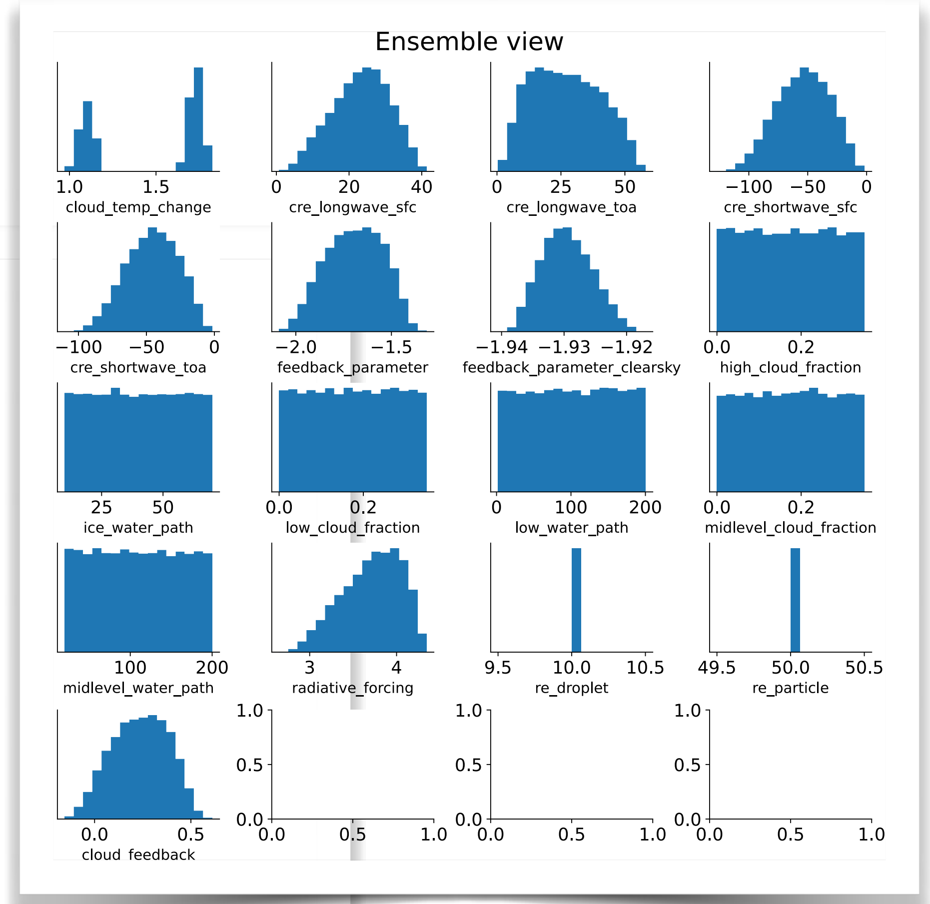


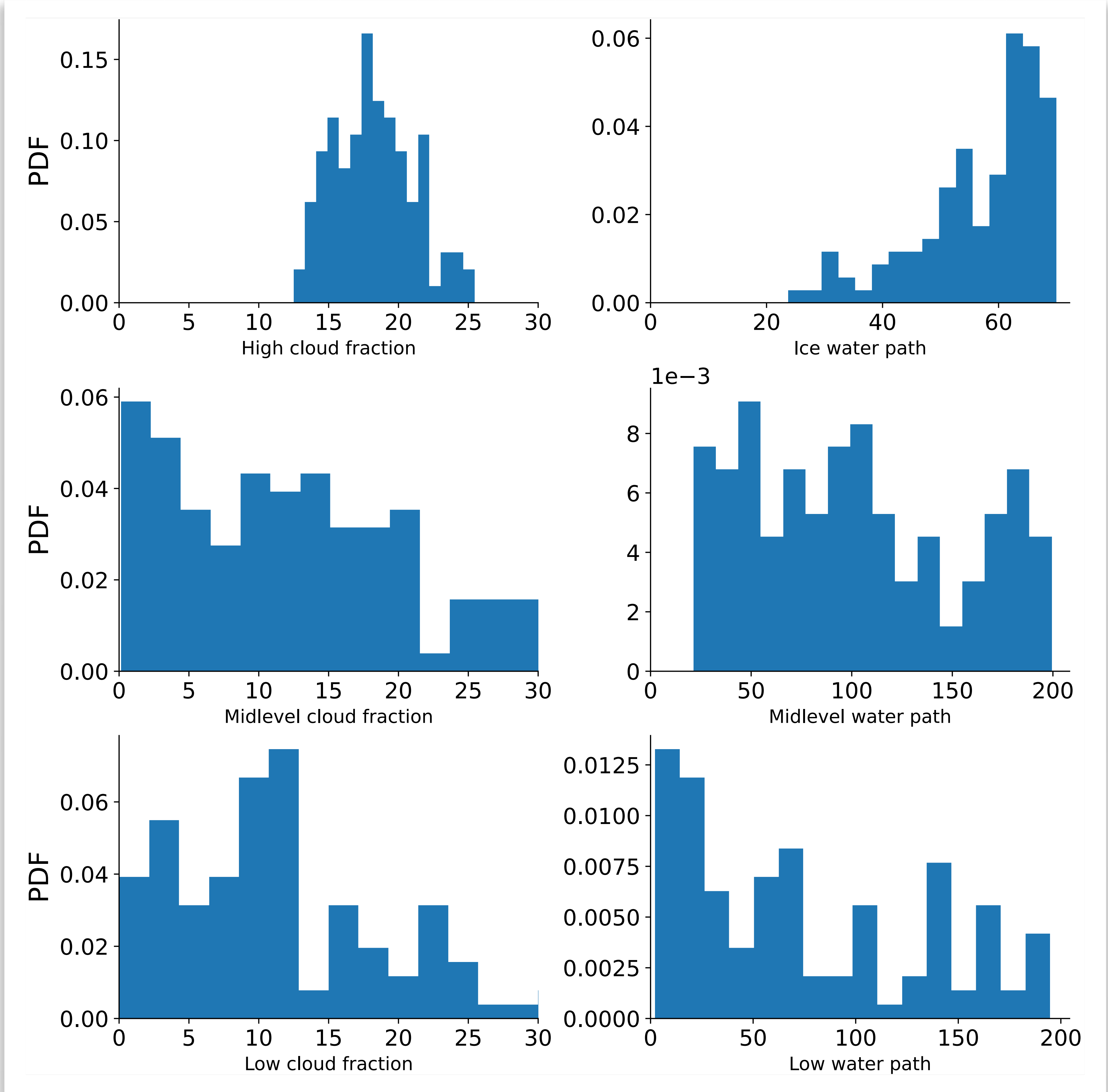


RCE with three level clouds, Kluft et al., in preparation (2022)

Selecting cloud distributions to match observed cloud radiative effects



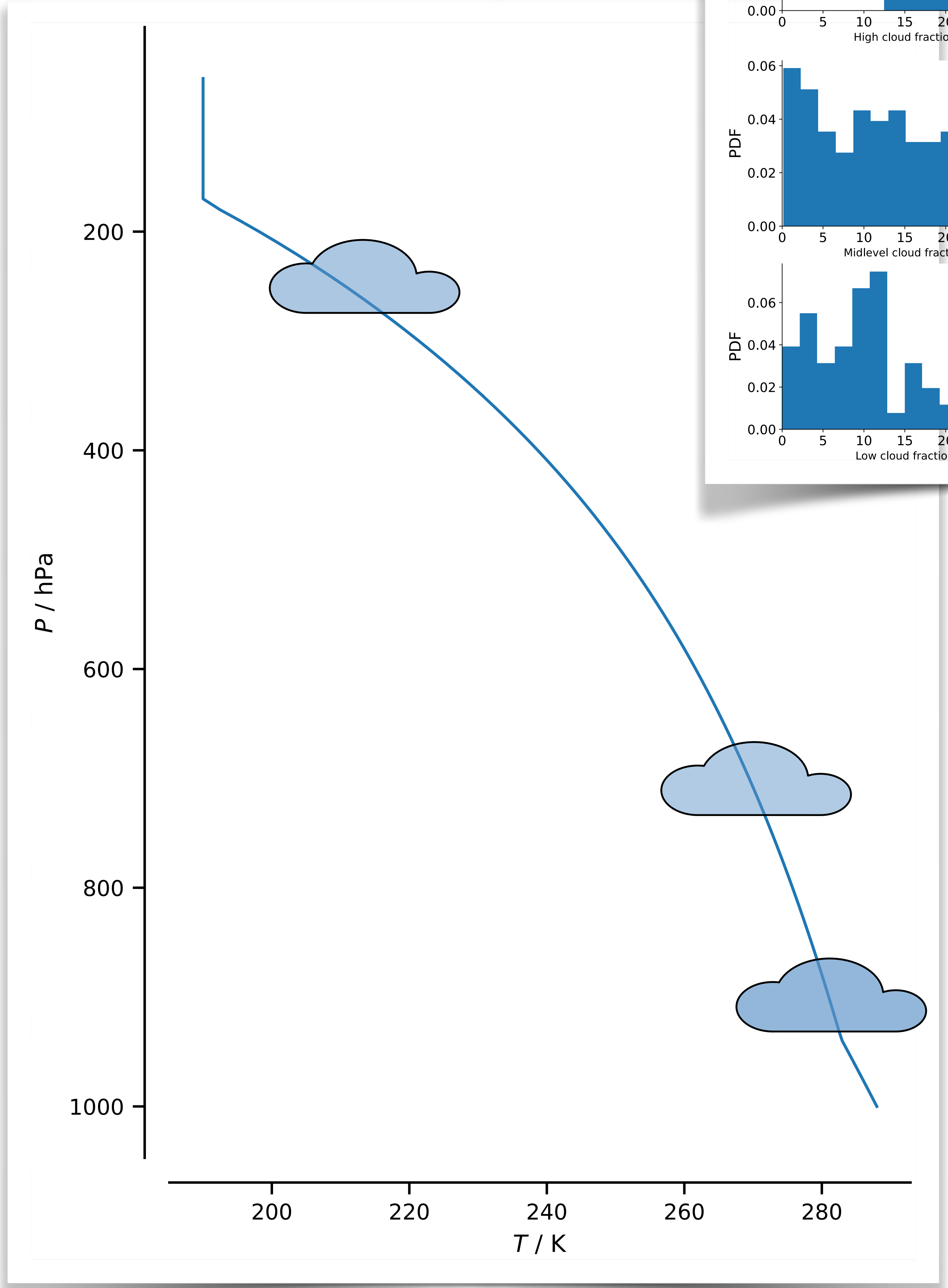


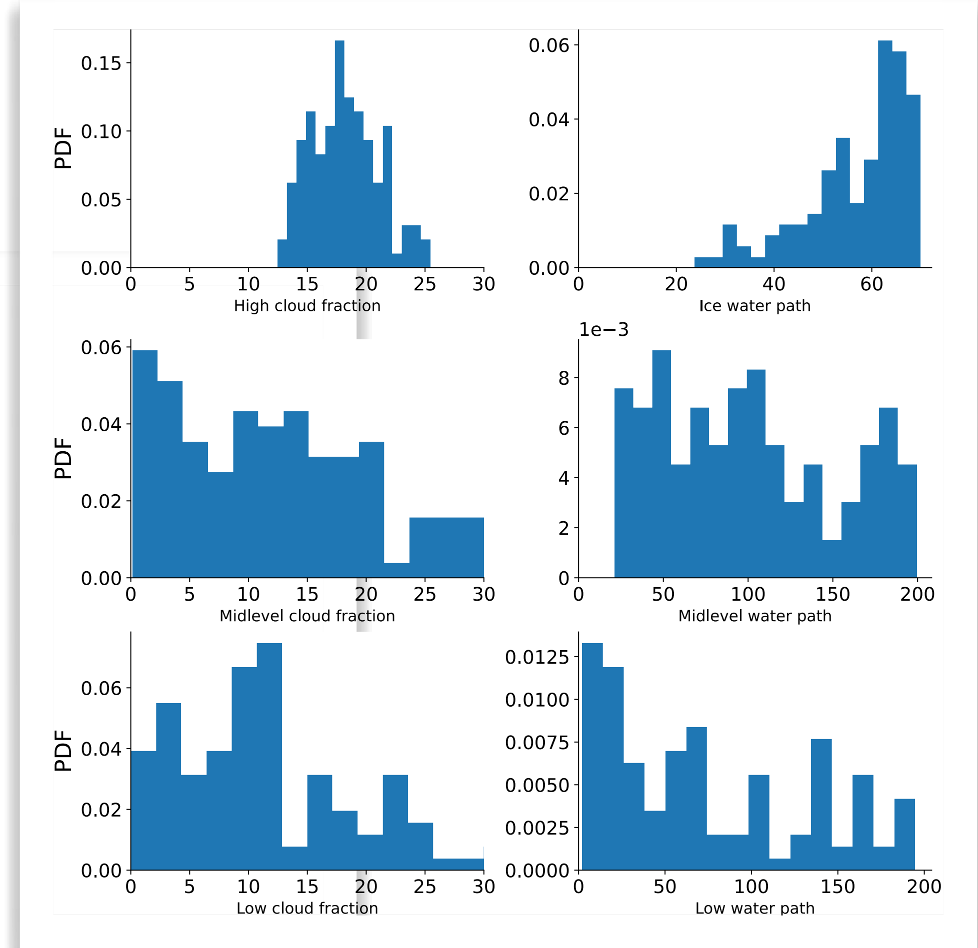


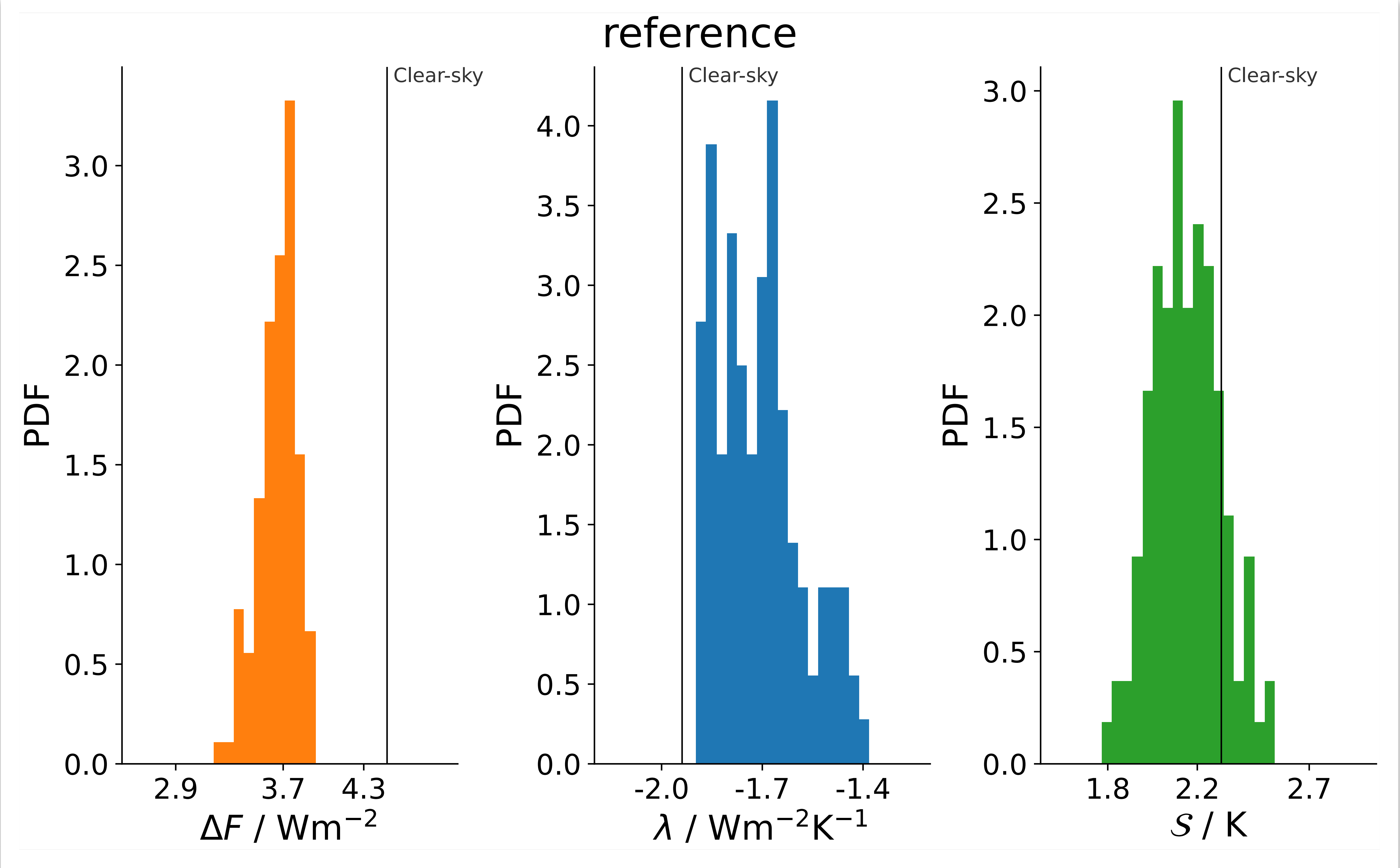
This works well, we can get reasonable cloud distributions and match surface and to a CRE to within about 1 Wm^{-2} in both LW and SW

RCE with three level clouds, Kluft et al., in preparation (2022)

Clouds don’t do much; but are more likely to mute than amplify warming







Clouds are expected to mask more response then forcing, but the moving (slight warming) of high and low clouds usually wins out

Including surface-albedo feedbacks

- The atmosphere masks surface albedo contribution to clear-sky fluxes.
- Using a simple one layer model we estimate a reduction of the surface reflection of slightly more than 40%
- Hence if the observed surface albedo feedback is 0.35 $\mathrm{Wm^{-2}}$, then without clouds it would be 0.6 $\mathrm{Wm^{-2}}$

$$\lambda = \lambda_{\mathrm{atm}} + \lambda_{\mathrm{sfc}} \approx -1.8\,\mathrm{Wm}^{-2}\mathrm{K}^{-1} + 0.6\,\mathrm{Wm}^{-2}\mathrm{K}^{-1} \approx -1.2\mathrm{Wm}^{-2}\mathrm{K}^{-1}$$

A cloud free Earth with the present ice coverage and surface temperature would have an ECS of ≈ 3.7 K

Masking based on calculations Crueger, Stevens and Schmidt, in preparation.

In a clouded atmosphere

- The forcing is less
- The surface albedo feedback is less
- Maybe some clouds go away, but not so much as to counter their cooling effect

$$\lambda = \lambda_{\mathrm{atm}} + \lambda_{\mathrm{sfc}} \approx -1.7\,\mathrm{Wm}^{-2}\mathrm{K}^{-1} + 0.35\,\mathrm{Wm}^{-2}\mathrm{K}^{-1} \approx -1.35\mathrm{Wm}^{-2}\mathrm{K}^{-1}$$

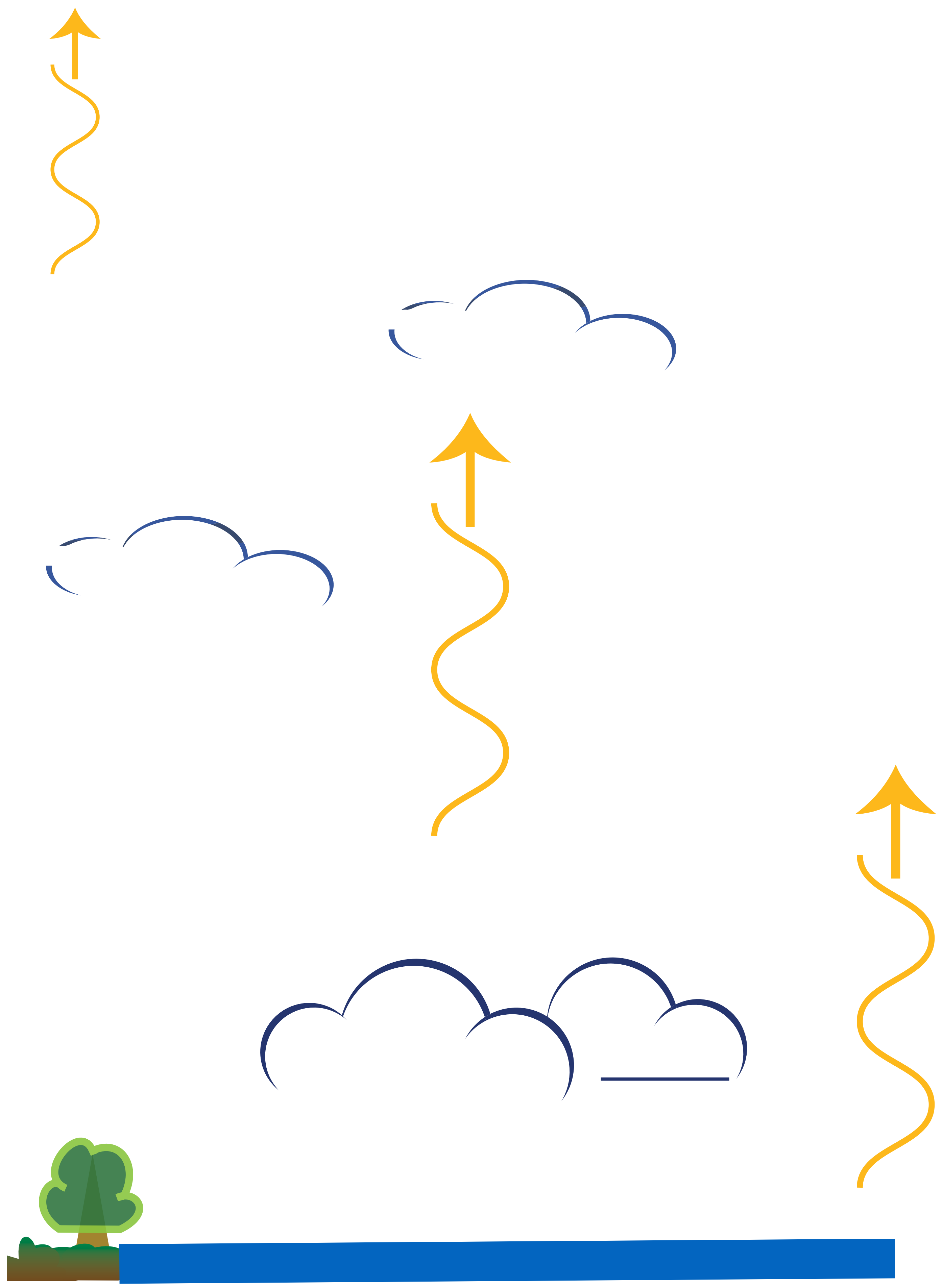
A cloudy earth would have an S of ≈ 2.74 K, or 3.2 K if we allow for +0.2 Wm^{-2} of SW cloud feedbacks.

What does this mean?

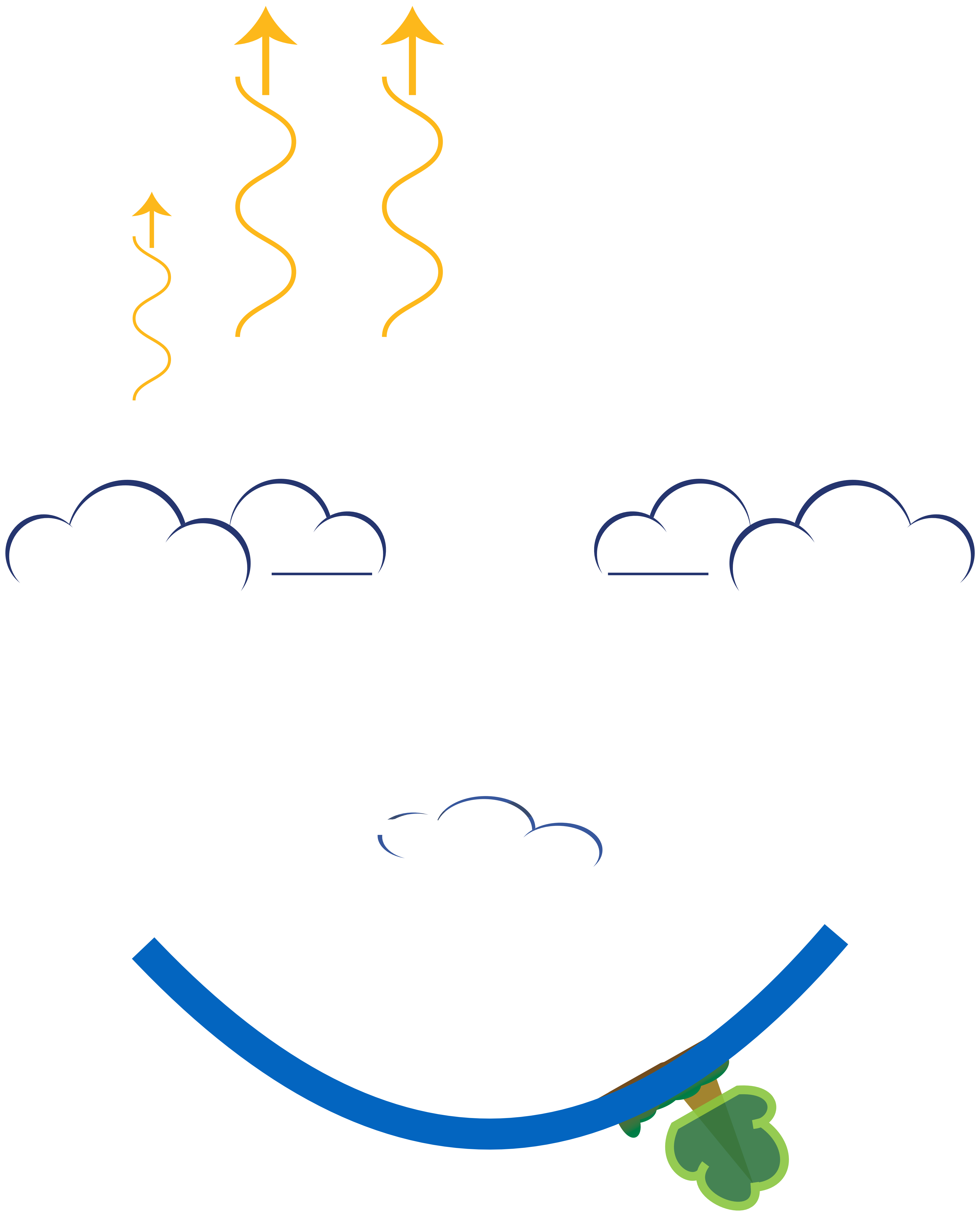
- The answer doesn't change much, if anything it brings the process understanding in line with other lower estimates — and supports the AR6 reasoning (well done Jean-Louis and Thorsten).
- It suggests that, if anything, clouds make the planet warm less then the clear-sky atmosphere would otherwise allow in response to doubling of CO_2
- My conceptualization changes how we reason from processes, as it starts from something we know, and adds things that we don't know, rather than by pretending that we don't know anything.

Reasoning from the clear sky is more transparent, and gives us more confidence in the answer.

… ridding clouds of their bad rap



… ridding clouds of their bad rap



Modulo CERES frightening SW trends